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DISCUSSION OF RETROGRESSION ON THE LOWER COLORADO RIVER AFTER 1935

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DISCUSSION

T. Blench,[2] M. ASCE.—In India, government research organizations and other organizations have been collecting data of boulder rivers and torrents for several years. They expect that eventually the data will show how to modify the formulas of regime theory[3,4] to apply to river conditions. In their present form, the formulas are applicable to canals that have attained regime with constant discharge (or known formative discharge), with sides in fair condition (so that they are technically "smooth"), and that are free from meandering. With the aid of engineering common sense, the formulas can be applied to a limited range of river problems; they could be applied even more widely if more attention were paid to collecting and using river data. The paper suggests that, not only is a desire growing on the American continent to make use of river data for regime predictions, but also the special semi-controlled conditions on the Colorado River (in Arizona-Nevada and Arizona-California) may permit a scientific analysis in terms of regime theory which will yield some positive results.

The regime formula of interest to the subject of the paper is

$$S = b^{\frac{5}{6}}\, s^{\frac{1}{12}}\, Q^{-\frac{1}{6}} \div (2{,}080\,(10^{-5}/\nu)^{\frac{1}{4}}) \qquad (2)$$

In Eq. 2, Q is the steady or known formative discharge; b is the bed factor; s is the side factor; ν is the mean kinematic viscosity; and S is the regime slope. The bed factor depends on the bed material, on the relative bed load, and on the suspended load; but no useful formula exists to relate these quantities. However, a constant bed factor is selected by reference to a constant V^2/y (V being the mean speed at formative discharge and y being the corresponding depth), which is used to define it. Upper and lower limits to the side factor are set by the resistance of the banks to erosion and the tendency for transported material to form banks. In the Colorado reaches under discussion the limited discharge may permit an assessment of formative discharge to be used directly in Eq. 2. The banks of a river may approximate (in places at least) those of canals, so that s can be estimated. The very small index of s permits it to be estimated with poor accuracy. The correction factor to be applied to S, as found from Eq. 2, should depend mainly on the meandering of the river instead of on several causes, as in uncontrolled rivers. This factor could then be estimated from the data inserted in Eq. 2 (for comparison with values found from experiments on the effect of curvature of flow on rate of loss of head) if b were known. As the relative bed load in the river must now be small, as in canals, the existence of regime canals having the same bed material as river reaches would permit estimates to be made for b. Even if canal data were lacking to permit an esti-

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[3] "The Behaviour and Control of Rivers and Canals," by Sir C. C. Inglis, Govt. of India Publication, Yeravda Prison Press, Poona, India, 1949.

[4] "Théorie de L'Écoulement Turbulent," by T. Blench, *La Houille Blanche*, May, 1946, p. 163.

mate of b, the application of the formula to river reaches with different bed materials, but with about the same degree of meandering, would give positive information on the variation of b with bed material. This would be helpful since the present admittedly empirical and rough condition (that b varies as the square root of the mean diameter) is based on some information in the range of 0.25-mm size and some for material of about 4-in. size.

The principal items of information required for analysis of a reach are: (*a*) Longitudinal sections (along the thalweg) of the water surface from the period when damming starts until stability occurs; (*b*) hydrograph of the reach for that time; (*c*) mechanical analyses of mobile bed material at intervals along the reach, at various times up until stability occurs, together with a detail of parts of the rigid bed; (*d*) statement of the nature of the banks at the formative stage; and (*e*) plan of the reach to show the meandering and tortuosity. For the latter purpose an air photo is best. If the writer were favored with such information for a considerable reach (even if for ultimate allegedly stable conditions only) he could probably assess the possibilities of a full analysis.

The general river behavior indicated in the paper is consistent with regime theory. As long as any sediment is in motion, aggradation must occur above Imperial Dam until a regime slope is reached, everywhere, compatible with that sediment and the sediment already on the bed. Reduction of dominant discharge (for example, by taking the peaks out of the river hydrograph) tends to increase regime slope. Exclusion of potential bed material tends to reduce regime slope. It is possible to imagine an increase of relative bed load below a junction if one arm remains heavily charged and the other arm, which was relatively lightly charged, has its dominant discharge reduced by damming. Exclusion of fine suspended load may increase the bed factor by upsetting the previous velocity distribution. Accretion may begin again, downstream from Imperial Dam, for any one of three reasons: (*a*) The river regime being established upstream may permit bed load to move downstream in increased quantities; (*b*) the dominant discharge may be reduced; and (*c*) the sediment excluded from the All-American Canal may be returned to the river.

EMORY W. LANE,[5] M. ASCE.—The changes that have taken place in the bed of the Colorado River below Lake Mead are typical of what can be expected in the future below many other hydraulic developments. By a careful study of these actions, engineers can avoid many difficulties in future cases. Mr. Stanley has rendered a useful service in making information available on these changes.

The aggradation above Imperial Dam occurred in a very undeveloped region where it caused no damage and attracted little attention. In several ways, however, the action in this river section is important as an illustration of what will occur over a short period of time as the result of the raising of the water level by a low dam on a graded stream carrying a heavy sediment load. It is even more important as an indication of what will happen over a longer period of years on streams carrying moderate sediment loads.

The data given by Mr. Stanley indicate that the deposition caused by the construction of Imperial Dam extended nearly four times as far upstream as

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the length of the level pool caused by the dam, and that the limit of this deposition extended to an elevation above the crest of the dam of more than three times the dam height. A much greater extension both in elevation and in distance would no doubt have occurred if it had not been stopped by the degrading action caused by Parker Dam. An examination of the records indicates that this action occurred almost entirely in the short period between the 1938 and 1944 observations. Had the natural flow of the river not been equalized by Hoover and Parker Dams, even more rapid action would have occured.

This is a very striking illustration of the fact that a dam on an alluvial river that is in equilibrium will cause deposits gradually extending farther and farther upstream, and the level of the deposit above the dam will tend to approach a slope equal to that of the river in its original condition, beginning at the crest of the dam. The rapidity of this trend depends largely on the storage volume available and the rate of sediment supply. In this case the deposits extended upstream from the crest of the dam and reached an average slope of about three fourths the original slope in about seven years. The action was rapid because the sediment load was great and because the storage volume below the crest level was comparatively small. Rough computations indicate that the sediment storage above the dam crest level was about 150% of that below the crest level, and that the deposits at the upper end of the level pool reached an elevation above the pool equal to about half the height of the dam.

The rapidity with which the Colorado River readjusted its slope above Imperial Dam should obviously serve as a warning to any one contemplating the construction of a dam on a stream carrying sediment loads where raising of the river bed above the level pool elevation will cause extensive damage. When one reflects that the same action will occur in many cases on other alluvial streams—but at a much slower rate—he cannot help but be glad that most streams carry much lower sediment loads than the Colorado River.

J. W. Stanley[6].—The information on regime formulas furnished by Mr. Blench is timely. The profession should take heed of his suggestion that the formulas could be applied much more widely to river problems if more attention were paid to collecting the necessary river data. Eq. 2 should have a more general application than Eq. 1 as given in the paper. The purpose of quoting Eq. 1 was to illustrate how it might be used in predicting future scour in the particular reach of the Colorado River referred to. In other words, it was desired to determine whether Eq. 1 is applicable to the Colorado River to the extent that it could be used to develop the trend line of decreasing rate of scour shown in Fig. 2.

As pointed out by Mr. Lane, the deposit above Imperial Dam would no doubt have extended much farther upstream had it not been for the control of the natural flow of the river by Hoover and Parker Dams, and the depositional action would have been even more rapid without these dams. In this instance, then, the existence of the dams simplified at least one problem on the Colorado River.

[6] Office of River Control, Region 3, Bureau of Reclamation, Boulder City, Nev.